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The Assessment of Effect of Fatty Acid Profile on the Physical Properties and Emission Characteristics of New Feedstocks Used for Biodiesel

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ABSTRACT

The present study uses three generations of biodiesels and studies their effects on physical properties and exhaust gases. They are comprised of *Palmaria palmate* oil (third generation), *Eucheuma spinosum* oil (third generation), *Eucheuma cottonii* oil (third generation), *Common wormwood* oil (second generation), *Marjoram* oil (second generation), *Peganum harmala* oil (second generation), *Zingiber officinale* oil (first generation), *Anethum graveolens* oil (first generation), and *Cacao bean* oil (first generation). Results show that first-generation oils gain a higher level of Calorific value around 41.16 MJ/kg than other generations. The longest carbon chain is observed by the first generation with higher unsaturated fatty acids than other generations (94.11 %). The first generation gains a higher level of density around 882 kg/m^3 than other generations. Also, the first generation gains a higher level of flash point around 193 ˚C than other generations. The third generation gains a high level of cetane number at about 69, compared to other generations. The first generation gains a minimum level of cloud and pour point around -3 ˚C and -2 ˚C compared to other generations. Moreover, the third generation gains the lowest level of viscosity about 2.51 CSt compared to the first generation. The third generation gains the lowest level of NO_x around 371 ppm compared to other generations. Finally, the third generation gains the lowest level of soot, CO, and HC around 0.47 Vol. %, 0.018 Vol. %, and 4.82 ppm, compared to other generations.

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1. INTRODUCTION

Fossil fuels face many problems today, the most important of which are price changes and their environmental problems. Furthermore, lack of sufficient resources and their proper distribution among countries have caused various crises. Therefore, the growing human need for alternative fuels is of utmost importance. Biofuels represent a good option with their benefits over fossil fuels. They are characterized by being highly biodegradable and renewable, being environmentally friendly, low toxicity, low combustion emission, high engine performance, advanced rural economic potential, combinable with diesel fuel at any ratio, and so on [1, 2].

The feedstock is a noteworthy cause for biodiesel production, as the production value should be cost effective. Biodiesels are now divided into four generations. The first generation is comprised of mint oil, colza oil, etc. They are considered as edible oils. The next generation encompasses jatropha oil, mahua oil, cottonseed oil, etc. They are considered as non-edible oils. The third generation is considered as microalgae oil, animal fat, and waste cooking oil. The last generation of biofuels is derived from genetically modified crops. This group is fixated on amalgamating feedstock biology, Carbon Capture Storage (CCS) processes, and producing high-quality biofuels and supreme performance efficiencies with zero carbon emission [3, 4].

The physical properties of biodiesels are displayed by the structural characteristics of fatty acids. Some of their physical characteristics are exhaust gas emissions, ignition quality, the heat of combustion, viscosity, density and lubricity, cold flow, and oxidative stability. The created biodiesel properties should meet the European standard specification (EN) 14214 or American Society for Testing and Materials (ASTM) D6751. Approaches that survey biodiesel properties include gas chromatography-mass spectroscopy (GC/MS), Fourier Transforms Infrared spectroscopy (FTIR), Nuclear Magnetic Resonance spectroscopy (NMR), and High-Performance Liquid Chromatography (HPLC) [5]. Numerous studies have shown that physical properties have an enormous effect on emission and combustion. Flashpoint, kinematic viscosity, boiling point, Cetane Number (CN), pour point, cloud point, heating value, and oxidative stability are the most significant physical properties affecting emission and combustion [6]. The fuel autoignition and CN are influenced by each other. The growth of CN triggers an effect on ignition quality [7]. Additionally, CN impacts the diesel combustion method by reducing the ignition delay. Thus, it lessens premixed combustion and also weakens the sudden spike at an

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in-cylinder temperature, which is responsible for enhancing the predisposition of thermal NO [8]. Hence, improving the CN triggers lessening the NO concentration. Folayan et al. indicated that palm kernel and coconut oil had upper pour and cloud point, low-temperature filterability, and cold filter plugging point and examination point compared to linoleic and oleic oils, which caused poor cold flow conduct. This is because these properties are considerably enhanced with a greater degree of unsaturation, longer carbon chain, and higher degrees of branching. Saponification number dropped with molecular weight and chain length. The iodine value rises as the mark of unsaturation rises, but drops with chain length. They also indicated the effect of fatty acids on CN, heating value, and density [9]. Marlina et al. worked on fatty acids and their results showed that polar fatty acids were further reactive because of electric charge. Bent and long polar fatty acids were more reactive than the straight and short polar ones, as the former had durable higher and polarity electron mobility. The uppermost electron mobility caused molecules to be less tight; therefore, evaporation level increased. The presence of more than one double bond in polyunsaturated oil partly inhibited electron mobility. Quicker evaporation level caused ignition temperature to decrease, meanwhile heat energy was altered in latent heat for stage change over evaporation [10]. Jafarihaghighi et al. used several samples and showed that the physical properties affected emissions. They showed that the structure of fatty acids decreased or increased physical properties and had a direct effect on exhaust emissions [11].

In this paper, the main objective is to show the physical properties and exhaust gases of three different generations of biodiesel under the same conditions to demonstrate which generation will have better efficiency and better outcomes. All the oils used are new to give a new perspective and eliminate the exclusivity of certain groups. In this path, the length of chains, ratio of hydrogen to carbon, oxygen to carbon, saturated acids, and unsaturated acids of the three generations are examined and compared. One of the most important reasons for choosing different generations in this report is that they have the ability to grow in harsh conditions in the Middle East and Iran, and that an attempt is made to show which future generation is better for use.

2. MATERIALS AND METHODS

Nine different oils from three different generations were considered. They include *Palmaria palmata* oil (third generation), *Eucheuma spinosum* oil (third generation), *Eucheuma cottonii* oil (third generation), *Common wormwood* oil (second generation), *Marjoram* oil (second generation), *Peganum harmala* oil (second generation), *Zingiber officinale* oil (first generation), *Anethum graveolens* oil (first generation), and *Cacao bean* oil (first generation). The methanol (99 %) and KOH (99 %) were supplied by Aldrich Chemical Co. (USA).

The transesterification technique was applied to the samples. Biodiesel samples were created through the KOH-catalyzed transesterification reaction at a level of 1 to 3 (v/v) for methanol-to-oil. Therefore, they were completed in the presence of KOH as the acid catalyst for around 1 h at 55-60 ˚C. Between one to two hours was adequate to separate the solution for eliminating methanol-water at the top stage. Then, in the bottom stage, the value of the acid level was calculated. The yields of biodiesel produced for first, second, and third generations of biodiesel were around 85-90 %, 89-95 %, and 93-95 %, respectively. All biodiesels were composed by a combination of 20 % net biofuel with 80 % diesel [1].

The flashpoint was calculated according to ASTM standard D93. The level of viscosity and value of density were determined with Stabinger Viscometer, Anton Paar, SVM3000 model (Anton Paar Co., Austria). The viscosity was also assessed by ASTM-D445. The flashpoint was calculated with the Constantly Close Cup Flash Point (CCCFP) tester applying the Grabner FLPH Miniflash Tester (Grabner, Austria). The level of cloud point was assessed by the s/500 (Italian) model, compliant with the ASTM standard D2500. Sediment and water measurements were completed by Karl Fischer setup, metrohm, 794 Basic Titrino model. Biodiesel mixtures, which were created with transesterification, were specified by Gas Chromatography (GC, Claus 580 GC model, Perkin Elmer Co., USA). The level of CN was shown by the Octan-IM device.

In this research, a 3LD 510 model was used for a 12-horsepower single-cylinder diesel engine manufactured by the Italian Lombardy Company. Its specifications are shown in Table 1. The dynamometer Eddy Current WE400 model from Pars Andish Innovative Company (MPA) was employed to measure the torque, rotational speed, and power of the 3LD 510 Diesel Engine. Specifications of the MAHA-MGT5 analyzer used in the test are shown in Table 2. The test was carried out at 2000 rpm and full load.

Table 1. The engine parameters

Specification	**Explanations**
Model	3LD510
Number of cylinders	1
Bore and stroke (mm)	85 × 90
Displacement (cm^3)	510
Aspiration	Naturally aspirated
Cycle	4 stroke
Combustion system	Direct Injection
Rotation	Counter-clockwise (view from main PTO side)
Cooling system	Air
Fuel tank capacity (l)	5.3
Oil sump capacity (l)	1.75
Length (mm)	466
Width (mm)	422
Height (mm)	568
Dry weight (kg)	60
Cylinder course (mm)	90
Cylinder diameter (mm)	85
Cylinder volume (cm^3)	510
Maximum power hp (3000 rpm)	12.2
Maximum torque 1800rpm (Nm)	33
Compression ratio	17.5:1

Table 2. Qualifications of the MAHA-MGT5 analyzer used in the test

Specification	Explanations
Measurable gases	HC, CO, CO_2, O_2, NO (Option)
Measuring principle Infrared spectrometry	HC, CO, CO_2
Measuring principle electrochemical detection	O_2, NO
Warm-up time	480 s
Flow	3.5 l/min
Working pressure	0.75 bar–1.1 bar
Accuracy class	O (OIML)
On-board voltage	12 V/42 V
Power supply	1/N/PE 85 V/285 V 50 Hz
Dimensions total (L × W × H)	240 mm × 560 mm × 300 mm
Weight	10 kg
CO - Measurement range / Measured value resolution (max.)	0-15 Vol. %/0.01
CO_2 - Measurement range / Measured value resolution (max.)	0-20 Vol. %/0.01
HC - Measurement range / Measured value resolution (max.)	0-9999 ppm/0.1 (Hexan) 0-20000 ppm/1 (Propan)
O_2 - Measurement range / Measured value resolution (max.)	0-25 Vol. %/0.01
Lambda (calculated)	0.5–9.99/0.01
NO (Option) - Measurement range / Measured value resolution (max.)	0-5000 ppm/1

3. RESULTS AND DISCUSSION

3.1. Physical properties

3.1.1. Structure of fatty acids

Fatty acids play an important role in the structure and emission of biodiesel. The carbon chain of different biodiesels ranged from C14 to C24. According to Table 3, the highest saturated acids for *Common wormwood* oil were Palmitic acids and also the highest unsaturated acids were Linoleic acids. The highest saturated acids for *Marjoram* oil were Palmitic acids and also the highest unsaturated acids were Oleic acids. The highest saturated acids for *Peganum harmala* oil were Palmitic acids and also the highest unsaturated acids were Oleic acids. The highest saturated acids for *Palmaria palmata* oil were Palmitic acids and also the highest unsaturated acids were Oleic acids. The highest saturated acids for *Eucheuma spinosum* oil were Palmitic acids and also the highest unsaturated acids were Linoleic acids. The highest saturated acids for *Eucheuma cottonii* algae oil were Palmitic acids and also the highest unsaturated acids were Oleic acids. The highest saturated acids for *Zingiber officinale* oil were Palmitic acids and also the highest unsaturated acids were Oleic acids. The highest saturated acids for *Anethum graveolens* oil were Palmitic acids and also the highest unsaturated acids were Oleic acids. The highest saturated acids for *Cacao bean* oil were Palmitic acids and also the highest unsaturated acids were Oleic acids.

Obviously, in Fig. 1, the longest carbon chain presented to *Anethum graveolens* biodiesel (C18-C24) was around 94.11 %. *Common wormwood* displayed a long carbon chain (C18-C22) around 93.35 %. Next, *Peganum harmala* displayed a long carbon chain (C18-C22) around 88.93 %. *Cacao bean* oil displayed a long carbon chain (C18-C20) around 88.47 %. Subsequently, *Marjoram* oil displayed a long carbon chain (C18-C22) around 86.73 %. *Zingiber officinale* oil displayed a long carbon chain (C18-C20) around 84.52 %. *Palmaria palmata* oil displayed a long carbon chain (C18-C22) around 80.19 %. *Eucheuma spinosum* oil displayed a long carbon chain (C18-C22) around 70.60 %. Finally, *Eucheuma cottonii* algae oil displayed a long carbon chain (C18-C20) around 58.40 %.

The presence of fatty acids in biodiesel can affect the rate of oxygen to carbon (O/C) and hydrogen to carbon (H/C). Vividly, the enhancement of fatty acids affects the amount of oxygen in the process. On the other hand, the amount of hydrogen can be altered by fatty acids. Therefore, the growth of saturated acids triggers the increase of hydrogen in the process. Hence, the maximum saturated acids, O/C, and H/C were gained by *Eucheuma cottonii*, *Eucheuma spinosum*, *Palmaria palmata*, *Zingiber officinale*, *Marjoram*, *Cacao bean*, *Peganum harmala, Common wormwood*, and *Anethum graveolens* biodiesels [2, 3].

Table 3. The result of physical and chemical properties of biodiesel sources

Fatty acid	***Common wormwood*** **% Wt**	***Marjoram*** **% Wt**	***Peganum harmala*** **% Wt**	***Palmaria palmata*** **% Wt**	***Eucheuma spinosum*** **% Wt**	***Eucheuma cottonii*** **% Wt**	***Zingiber officinale*** **% Wt**	***Anethum graveolens*** **% Wt**	***Cacao bean*** **% Wt**
Caprylic (C8:0)	-	-	-	-	-	-	-	-	-
Capric (C10:0)	-	-	-	-	-	-	-	-	-
Lauric (C12:0)	-	-	-	-	-	-	-	-	-
Myristic (C14:0)	-	-	-	-	-	-	-	-	-
Myristoleic (C14:1)	-	-	-	-	-	-	-	-	-
Pentadecanoic (C15:0)	-	-	-	-	-	-	-	-	1.28

Palmitic (C16:0)	7.78	13.13	10.92	15.92	23.75	37.41	11.71	5.89	9.77
Palmitoleic (C16:1)	-	-	0.19	2.96	2.97	-	-	-	2.55
Heptadecanoate (C17:0)	-	-	-	-	-	-	2.40	-	-
Stearic (C18:0)	2.35	3.20	5.16	3.60	5.01	4.70	9.31	1.09	1.35
Oleic (C18:1)	30.30	16.32	56.40	60.48	23.05	29.09	50.09	45.60	47.03
Linoleic (C18:2)	59.14	24.11	14.50	10.60	35.16	21.34	22.80	22.16	35.83
Linolenic (C18:3)	0.41	41.17	9.00	2.80	6.07	2.25	0.31	7.38	1.30
Arachidic (C20:0)	0.49	0	1.89	1.77	3.72	1.02	2.01	2.51	0.96
Gondoic (C20:1)	-	0.56	1.10	-	-	-	-	-	-
Behenic (C22:0)	0.66	1.30	0.88	-	-	-	-	2.82	
Erocic (C22:1)	-	0.21	-	0.94	-	-	-	-	-
Lignoceric (C24:0)	-	-	-	-	-	-	-	4.02	-
Nervonic (C24:1)	-	-	-	-	-	-	-	8.53	-
Total	100	100	100	100	100	100	100	100	100

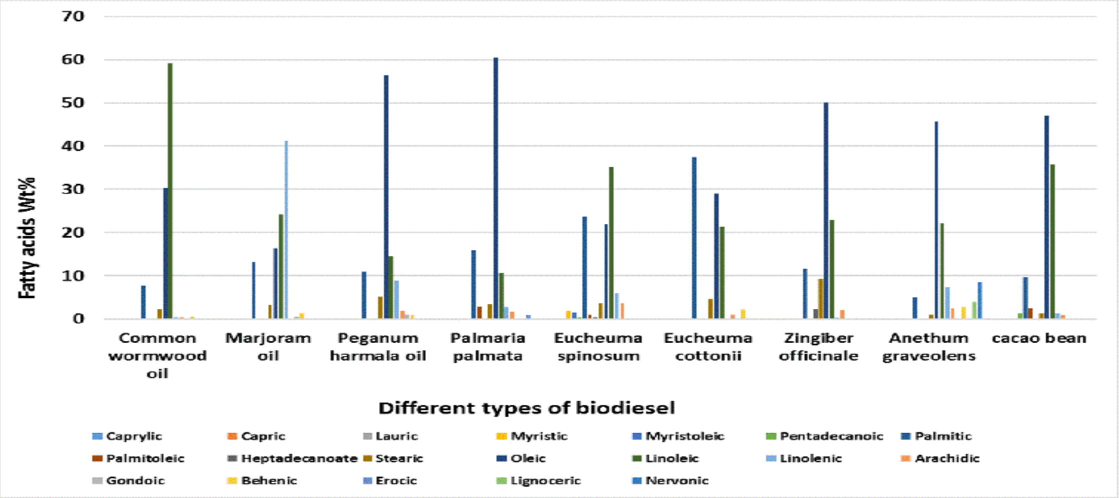

Figure 1. The highest amount of fatty acids in various biodiesel sources

3.1.2. Calorific value (CV)

The heat of combustion (CV) of fuels is a noteworthy measurable parameter, as it can represent the quantity of heat liberated with fuels in the engine that empowers the engines to prepare the work. Fig. 2 displays that greater CV is obtained by *Anethum graveolens* biodiesel around 43.21 MJ/kg. *Common wormwood* biodiesel acquired the second place and it was around 41.16 MJ/kg. The least level of CV was revealed by *Eucheuma cottonii* biodiesel close to 34.97 MJ/kg. The list was continued with *Peganum harmala*, *Cacao bean*, *Marjoram*, *Zingiber officinale*, *Palmaria palmata*, and *Eucheuma spinosum* biodiesel around approximately 37.58, 37.02, 36.12, 36, 35.19, and 35.07 MJ/kg, respectively. According to Fig. 2, the third generation of biodiesel gained the lowest amount of CV; however, the difference between them was low. The first generation of biodiesel showed better results than the second and third generations. Regarding Figure 1, the longest carbon chain is revealed by *Anethum graveolens* biodiesel; consequently, the supreme CV level was observed by it. However, the shortest carbon chain was demonstrated by *Eucheuma cottonii* biodiesel, which had the lowest CV among all biodiesels [4, 5]. The carbon chain had a direct effect on CV and triggered the growth of CV of biodiesels. In fact, the increase of carbon chain could enhance the amount of molecular mass, increasing CV. Ogbu et al. used *Cucurbita pepo*, *Afzelia africana*, and *Hura crepitans* oil and achieved the same results, indicating that CV and carbon chain were interconnected [6].

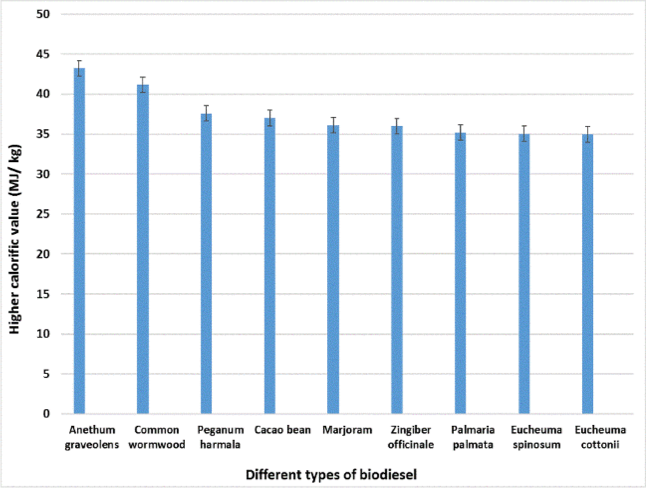

Figure 2. The upper calorific value in numerous biodiesel sources

3.1.3. Density

Density is considered as momentous fuel characteristic, as injection systems, pumps, and injectors must convey the quantity of fuel precisely adjusted to provide precise combustion. Therefore, one of the parameters that contributes to the advancement in biodiesel source density is their molecular weight. The level of density of fuel has an impact on the engine act properties. The superior density will escalate the diameter of fuel droplets. Thus, fuels with slighter density will enhance the efficiency of air-fuel combination formation and atomization. Consequently, *Anethum graveolens* biodiesel had the highest level of density around 882 kg/m^3 (Fig. 3). However, the least density was seen by *Eucheuma cottonii* biodiesel, which was roughly 850 kg/m^3. The list was continued with *Common wormwood*, *Peganum harmala*, *Cacao bean*, *Marjoram*, *Zingiber officinale*, *Palmaria palmata*, and *Eucheuma spinosum* biodiesel, with approximate levels of 880, 876, 871, 869, 863, 857, and 855 kg/m^3, respectively. As shown in Fig. 1, the longest carbon chain and double bond number affected density and enhanced this parameter. *Anethum graveolens* biodiesel had the longest and greatest number of double bonds (94.11 Wt %), which had the highest density level among all the biodiesel samples in contrast to *Eucheuma cottonii* biodiesel (58.40 Wt %). Therefore, the third generation of biodiesel had the lowest amount of density; however, the difference among them was low. Almost, the first generation of biodiesel showed better results than the second and third generations [2]. The fatty acids influenced the density; thus, the growth of the carbon chain and double bonds boosted the level of these characteristics. Mer et al. applied Karanja and Palm oil in their study, showing that carbon chain and double bonds could affect the density level, which complied with the results of this study [7].

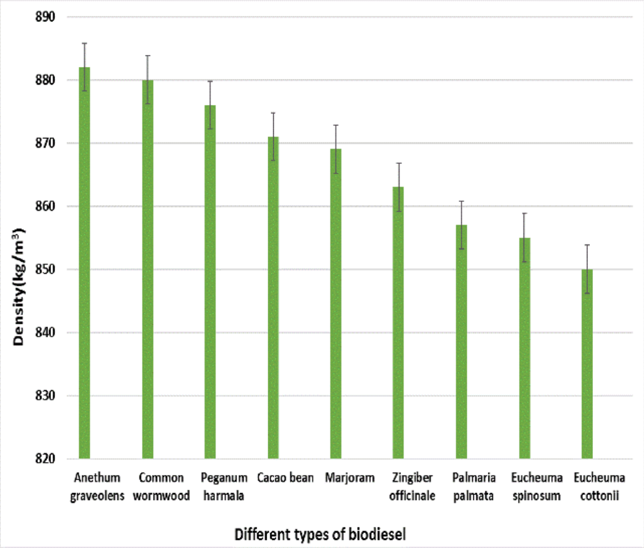

Figure 3. The density level in various biodiesel sources

3.1.4. Flash point

The flashpoint is considered as a temperature at which the fuel commences to burn while it comes to contact with fire. It is vitally important with regard to fuel handling, transportation, and storage. Biodiesels normally have a higher flash point than diesel fuels. There are some parameters such as the number of double bonds, residual alcohol content, and number of carbon atoms that could influence flashpoint. Similar results were found in the study of Mer et al. and Ogbu et al., indicating the impact of double bonds and carbon atoms [6, 7]. Among the oils used in this study, *Anethum graveolens* biodiesel had the highest level of flashpoint around 193 ˚C (Fig. 4), whereas the least flashpoint level was seen in *Eucheuma cottonii* biodiesel, which was roughly 174.6 ˚C. The list continued with *Common wormwood*, *Peganum harmala*, *Cacao bean*, *Marjoram*, *Zingiber officinale*, *Palmaria palmata*, and *Eucheuma spinosum* biodiesel with approximate flashpoint levels of 190.1, 188.7, 185.9, 181.5, 179.2, 177.7, and 175.6 ˚C, respectively. *Anethum graveolens* biodiesel had the longest double bonds and carbon chain among other samples, which was around 94.11 Wt%. Among all the samples, *Eucheuma cottonii* biodiesel had the shortest carbon chain length and double bonds, being 58.40 Wt % (Fig. 1). Therefore, the third generation of biodiesel had the lowest amount of flashpoint. The first generation of biodiesel showed better results than the second and third generations.

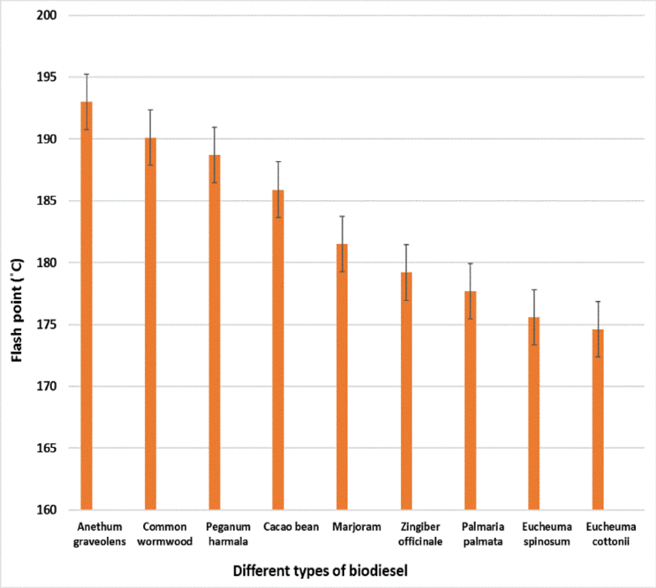

Figure 4. The flash point quantity in different biodiesel sources

3.1.5. Cetane number (CN)

CN is a reverse function of a fuel's ignition delay and it is the period between the ignition start and the first identifiable pressure rise over fuel combustion. In a specific diesel engine, upper CN had a shorter ignition delay period than the lower CN. In this regard, *Eucheuma cottonii* biodiesel had the highest level of CN around 69 (Fig. 5), whereas the least of the CN was observed in *Anethum graveolens* biodiesel that was roughly 55. The list continued with *Eucheuma spinosum*, *Palmaria palmata*, *Zingiber officinale*, *Marjoram*, *Cacao bean*, *Peganum harmala*, and *Common wormwood* biodiesel with approximate CN levels of 67, 67, 65, 64, 62, 60, and 59, respectively. The growth of carbon chain length and unsaturated acids affected CN development [8]. However, our results showed that the effect of unsaturated acids was greater than the chain length, which led to greater CN changes. The results of this study are in line with the study of Ogbu et al. [3, 6]. Moreover, the highest amount of saturated acids was obtained by *Anethum graveolens* and the minimum was achieved by *Eucheuma cottonii* biodiesel. Consequently, the third generation of biodiesel gained the highest amount of CN. Almost, the first generation of biodiesel showed less significant results than the second and third generations.

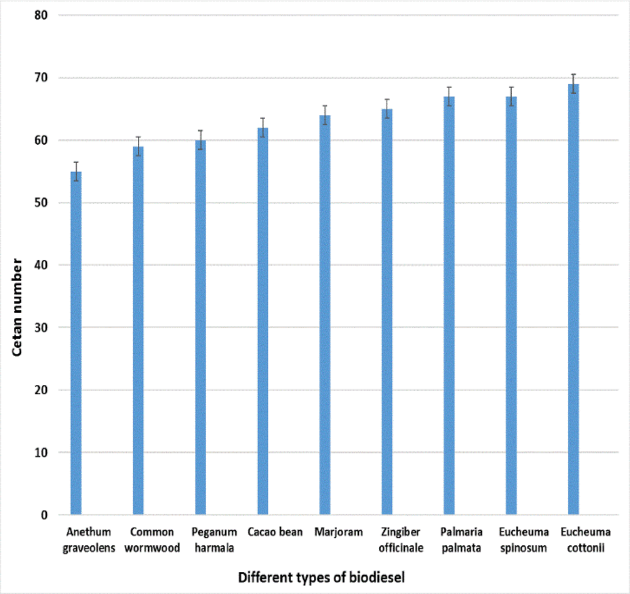

Figure. 5. The CN value in different biodiesel sources

3.1.6. Cloud and pour point

Pour point is identified as the lowest temperature that fuels can flow. Also, cloud point is renowned for the bottommost temperature where the cloud of wax crystals is formed while cooled. Both parameters in biodiesel are at a higher level than diesel fuels because of a higher level of saturated fatty acids, making it difficult in cold climate circumstances. Biodiesels with a notable level of saturated fatty compounds had a higher pour point and cloud point. In some studies, it has been reported that the chain length increase affects these points, being consistent with the current results because increasing the chain length increases the amount of unsaturated acids, thus changing these points [9, 10]. In this regard, *Anethum graveolens* biodiesel had the lowest level of cloud point around -3 ˚C (Fig. 6), whereas the highest cloud point was exposed by *Eucheuma cottonii* biodiesel that was roughly 6 ˚C. The list continued with *Common wormwood*, *Peganum harmala*, *Cacao bean*, *Marjoram*, *Zingiber officinale*, *Palmaria palmata*, and *Eucheuma spinosum* biodiesel with approximate cloud points of -2, -1, 1, 2, 3, 3, and 4 ˚C, respectively. *Anethum graveolens* biodiesel had the lowest level of pour point around -2 ˚C (Fig. 6), whereas the highest pour point was exposed by *Eucheuma cottonii* biodiesel that was roughly 8 ˚C. The list continued with *Common wormwood*, *Peganum harmala*, *Cacao bean*, *Marjoram*, *Zingiber officinale*, *Palmaria palmata*, and *Eucheuma spinosum* biodiesel with approximate pour points of 1, 1, 3, 5, 5, 6, and 6 ˚C, respectively. *Eucheuma cottonii* biodiesel had the highest level of saturated acids (more than 46 %), thus improving both parameters. Therefore, the third generation of biodiesel gained the highest level of pour and cloud points. The first generation of biodiesel showed better results than the second and third generations.

3.1.7. Viscosity

The enhancement of the level of viscosity caused several issues in the engine. Some of them are poor atomization, excess penetration, and poor mixing with air. The level of viscosity can be lessened via pre-heating the oil through a transesterification method. In this regard, *Anethum graveolens* biodiesel had the highest level of viscosity around 3.11 CSt (Fig. 7). However, the lowest viscosity level was observed by *Eucheuma cottonii* biodiesel that was roughly 2.51 CSt. The list continued with *Common wormwood*, *Peganum harmala*, *Cacao bean*, *Marjoram*, *Zingiber officinale*, *Palmaria palmata*, and *Eucheuma spinosum* biodiesel with approximate viscosity levels of 3.13, 3.04, 3, 2.94, 2.88, 2.73, and 2.69 CSt, respectively. Furthermore, the viscosity advanced with the ester chain and *Anethum graveolens* biodiesel had the longest carbon chain among all the samples in contrast to *Eucheuma cottonii* biodiesel [11, 12]. Numerous reports indicated that chain length had the highest effect on viscosity [10, 13]. However, in a recent study, it was shown that the amount of saturated and unsaturated acids could also have a direct effect on viscosity, which contradicted the results of previous reports that point to the low effect of this factor [6]. Therefore, the third generation of biodiesel had the lowest amount of viscosity. Almost, the first generation of biodiesel showed better results than the second and third generations.

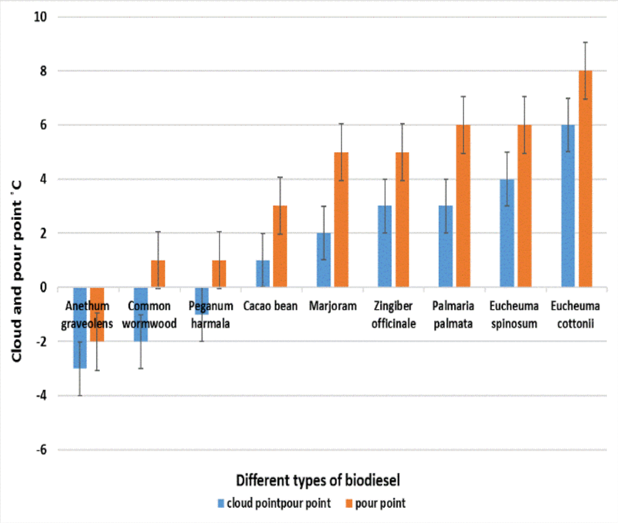

Figure 6. The cloud and pour rate in different biodiesel sources

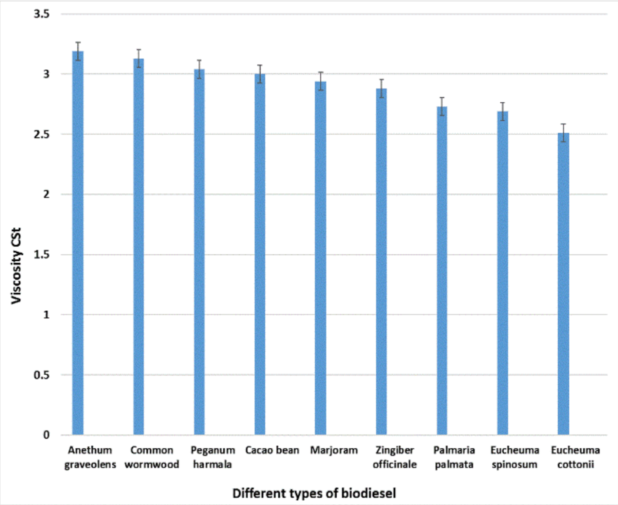

Figure 7. The viscosity level in different biodiesel sources

3.2. EMISSIONS

3.2.1. NO_x emission

The ignition quality is normally connected to CN and the great CN level demonstrates short ignition delay. So, it implies minimum fuel energy in the premixed phase that triggers lower NO_x emissions through the premixed phase. Therefore, in Table 4, the *Anethum graveolens* showed maximum NO_x emission at around 470 ppm, with the bottommost CN among all the samples. The bottommost NO_x emission was related to *Eucheuma cottonii* biodiesel that had the highest level of CN among the samples. The list continued with *Common wormwood*, *Peganum harmala*, *Cacao bean*, *Marjoram*, *Zingiber officinale*, *Palmaria palmata*, and *Eucheuma spinosum* biodiesel, respectively. The results showed that lessening CN level affected the progress of NO_x [14-16]. Furthermore, NO_x construction is subject to combustion duration, exclusive temperature, and volumetric efficiency arising from great activation energy connected to the reactions involved. Also, the influence of carbon chain and unsaturated acids on NO_x emissions is shown [17, 18]. Therefore, according to Fig. 8, the maximum level of unsaturated acids and the minimum level of CN were observed by *Anethum graveolens* biodiesel in contrast to *Eucheuma cottonii* biodiesel; therefore, the highest amount of NO_x was emitted by this biodiesel due to the enhanced ignition delay and amount of premixed combustion [3]. Increased O/C level improved NO_x emission in biodiesels. The burning reaction stoichiometry and the thermal NO_x formation mechanisms exhibited that enlarged oxygen rate improved NO_x emissions. With reference to the O/C level and NO_x emissions, the escalation of the O/C ratio indicated shorter chains and further oxygen in the procedure that assisted generating more NO_x output. Consequently, the *Eucheuma cottonii* biodiesel with the greatest quantity of unsaturated acids had the bottommost O/C ratio. Moreover, the lowest oxygen content decreased NO_x emissions [19]. Therefore, the third generation of biodiesel caused the lowest amount of NO_x emission. The first generation of biodiesel showed almost higher results than the second and third generations.

Table 4. The amount of NO_x in different sources

Biodiesels	**Exhaust emission**
	NO_x ppm
Anethum graveolens	470
Common wormwood	467
Peganum harmala	443
Cacao bean	438
Marjoram	415
Zingiber officinale	396
Palmaria palmata	382
Eucheuma spinosum	377
Eucheuma cottonii	371

3.2.2. Soot emission

Table 5 shows soot emissions of several biodiesel sources. The *Anethum graveolens* showed maximum soot emission around 0.83 Vol. %. The bottommost soot emission is related to *Eucheuma cottonii* biodiesel. The list continued with *Common wormwood*, *Peganum harmala*, *Cacao bean*, *Marjoram*, *Zingiber officinale*, *Palmaria palmata*, and *Eucheuma spinosum* biodiesel, respectively.

Some parameters, such as the rise of the carbon chain, affect soot emission. Therefore, the longest chain was seen in *Anethum graveolens* biodiesel around 94.11 %. In fact, the upsurge of *Anethum graveolens* carbon chain improved the soot level that touched 0.83 Vol. %. The *Common wormwood* biodiesel was in the second place with a carbon chain of about 93.35 % and soot level of virtually 0.78 Vol. %. *Eucheuma cottonii* biodiesel had the shortest carbon chain that was only 58.40 % in the array of C18 – C24. Consequently, this caused a decline in soot emission levels. Results do not comply with those of the former study which indicated that the upsurge of carbon chain did not increase the soot levels [24, 20]. This occurred due to the oxygen content in biodiesels, which was reduced with the upsurge of the carbon chain. Higher oxygen content reduced soot level. The results demonstrated that the highest oxygen content was seen in *Eucheuma cottonii* biodiesel. The level of O/C belonged to *Eucheuma cottonii* biodiesel. *Anethum graveolens* biodiesel had the bottommost O/C level, which had improved soot emissions [3, 21].

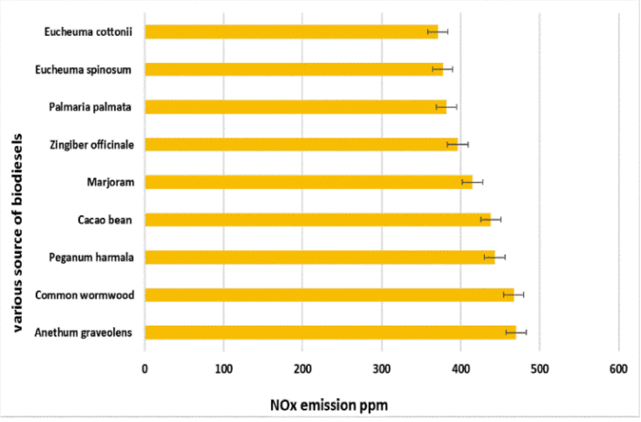

Figure 8. The level of NO_x emissions in different biodiesel sources

The greatest quantity of unsaturated acids was seen in *Anethum graveolens* biodiesel (94.11 %) and the minimum was observed in *Eucheuma cottonii* biodiesel. In the experiments conducted in this study, a direct link was observed between the improvement of unsaturated acid number and the soot level. As the number of unsaturated acids improved, the rate of soot level enhanced. The lowest quantity of unsaturated acids was linked to *Eucheuma cottonii* biodiesel (58.40 %), which caused the bottommost soot level. Increasing the number of unsaturated acids in the models boosted the number of the binary bonds, elevating the quantity of soot yield [22, 23]. The H/C ratio exhibited the level of saturated acids. The improvement of this level had an indirect effect on soot outputs since soot emission declines while the fuel burns well. Therefore, the third generation of biodiesel had the lowest amount of soot emission. The first generation of biodiesel showed almost better results than the second and third generations.

Table 5. The amount of soot in different sources

Biodiesels	**Exhaust emission**
	Soot Vol. %
Anethum graveolens	0.83
Common wormwood	0.78
Peganum harmala	0.74
Cacao bean	0.69
Marjoram	0.66
Zingiber officinale	0.63
Palmaria palmata	0.57
Eucheuma spinosum	0.52
Eucheuma cottonii	0.47

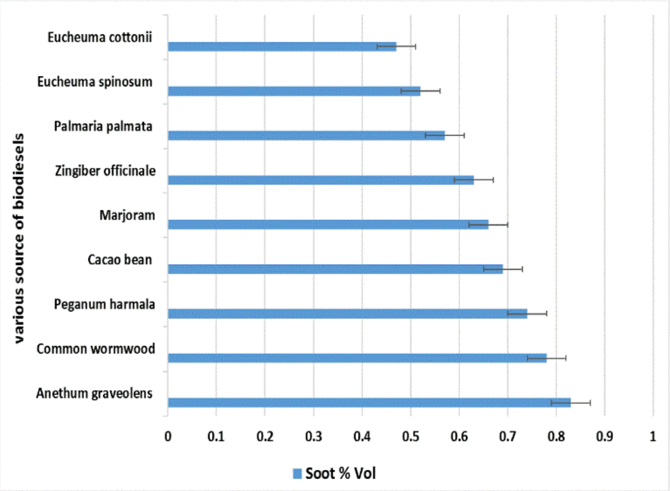

Figure 9. Soot emission levels in different biodiesel sources

3.2.2. CO emissions

The quantity of CO emissions of various biodiesel sources is shown in Fig. 10. The *Anethum graveolens* showed the highest CO emission around 0.038 Vol. %. The lowest HC emission was linked to *Eucheuma cottonii* biodiesel. The list continued with *Common wormwood*, *Peganum harmala*, *Cacao bean*, *Marjoram*, *Zingiber officinale*, *Palmaria palmata*, and *Eucheuma spinosum* biodiesel, respectively.

The lessening of CO emissions perhaps occurred due to the oxygen, leading to easier burning at upper temperatures in cylinders. This is demonstrated by the greater oxygen content in the shorter carbon chain that resulted in cleaner and further complete combustion. Besides, there were methyl esters in longer chains that had upper melting and boiling points, which were less probable to be entirely vaporized and burnt, thus promoting CO level. According to Table 6, the longest chain as well as the lowest O/C among all samples were seen in *Anethum graveolens* biodiesel (94.11 %), contributing to an opposite link between O/C and CO [24, 25]. Therefore, the third generation of biodiesel had the lowest amount of CO emission. The first generation of biodiesel showed almost better results than the second and third generations.

Table 6. CO emission for biodiesel sources

Biodiesels	**Exhaust emission**
	CO emissions (% Vol)
Anethum graveolens	0.038
Common wormwood	0.036
Peganum harmala	0.035
Cacao bean	0.032
Marjoram	0.028
Zingiber officinale	0.025
Palmaria palmate	0.024
Eucheuma spinosum	0.022
Eucheuma cottonii	0.018

3.2.3. HC emissions

The quantity of HC emissions of samples is shown in Fig. 11. The *Anethum graveolens* had the highest HC emission around 6.23 ppm. The lowest HC emission was seen in *Eucheuma cottonii* biodiesel. The list continued with *Common wormwood*, *Peganum harmala*, *Cacao bean*, *Marjoram*, *Zingiber officinale*, Palmaria palmata, and *Eucheuma spinosum* biodiesel, respectively. According to Table 3, carbon-chain improved HC level due to the extended chain length and greater boiling point. This improvement is the reason for the lessening of O/C rate and an upsurge of HC amount due to inferior oxygen content [3, 26]. Therefore, the third generation of biodiesel had the lowest amount of HC emission. The first generation of biodiesel showed almost better results than second and third generations.

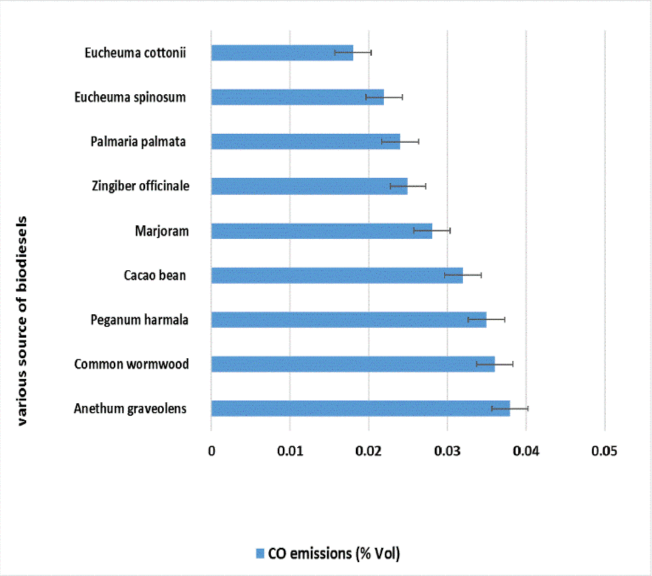

Figure 10. CO emission levels in different biodiesel sources

Table 7. HC emission for biodiesel sources

Biodiesels	**Exhaust emission**
	HC emissions (ppm)
Anethum graveolens	6.23
Common wormwood	6.10
Peganum harmala	5.85
Cacao bean	5.46
Marjoram	5.33
Zingiber officinale	5.07
Palmaria palmata	4.97
Eucheuma spinosum	4.86
Eucheuma cottonii	4.82

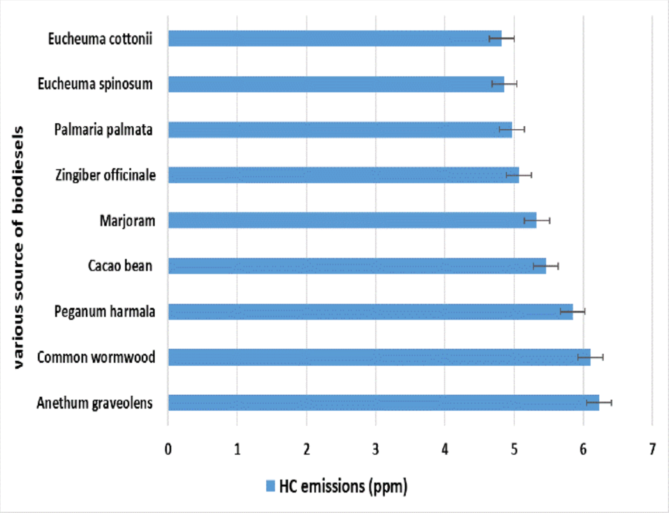

Figure 11. The HC emission levels in different biodiesel sources

4. CONCLUSIONS

In this study, we studied nine different types of biodiesels. These biodiesel types are of different generations, making it possible to show a complete view of the differences between the first and third generations. The main research objective was to investigate fatty acids, their physical properties as well as exhaust gases to compare the three generations. The results are given below:

- Nine different oils from three generations of biodiesels were examined. All species are capable of growing in most parts of the world and are able to grow in harsh climates.
- The longest carbon chains belonged to the first and second generations of biodiesel, while the third generation had more saturated acids and shorter carbon chains than the other generations.
- The third generation of biodiesel had the lowest quantity of CV. The first generation of biodiesel had better results than the second and third generations. Besides, the carbon chain could affect the CV level.
- The third generation of biodiesel had the lowest amount of density; almost the first generation of biodiesel showed better results than the second and third generations. Also, the carbon chain and double bonds could affect the level of density.
- The third generation of biodiesel had the lowest amount of flashpoint; almost, the first generation of biodiesel showed better results than the second and third generations. In addition, the carbon chain and double bonds could affect the level of flashpoint.
- The third generation of biodiesel had the highest amount of CN. The first generation of biodiesel showed lower results than the second and third generations. In addition, the carbon chain and saturated acids could affect the level of CN.
- The third generation of biodiesel had the highest level of pour and cloud points. The first generation of biodiesel showed better results compared to the second and third generations. In addition, the saturated acids could affect the level of pour and cloud points.
- The third generation of biodiesel had the lowest amount of viscosity. The first generation of biodiesel showed better results than the second and third generation. In addition, the carbon chain could affect the level of viscosity.
- The third generation of biodiesel had the lowest amount of NO_x emission. The first generation of biodiesel showed better results than the second and third generations. Also, some factors such as O/C ratio, carbon-chain, and CN can manipulate the level of NO_x emission.
- The third generation of biodiesel had the lowest amount of soot emission. The first generation of biodiesel showed better results than the second and third generations. Besides, some factors, such as O/C ratio, carbon-chain, H/C ratio, and saturated and unsaturated acids could change the level of NO_x emission.
- The third generation of biodiesel had the lowest amount of CO emission. The first generation of biodiesel showed higher results than the second and third generations. There are some parameters that could alter the level of CO, such as O/C ratio, carbon-chain, and oxygen content.
- The third generation of biodiesel had the lowest amount of HC emission. The first generation of biodiesel showed better results than the second and third generations. There are some parameters that could alter the level of HC such as O/C ratio, carbon-chain, and oxygen content.

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NOMENCLATURE

NO_x	Nitrogen oxides
KOH	Potassium hydroxide
ASTM	American Society for Testing and Materials
EN	European standard
CN	Cetane number
O/C	Oxygen to carbon
H/C	Hydrogen to carbon
HC	Unburned hydrocarbons
CO	Carbon monoxide

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